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RESEARCH NEEDS IN STRUCTURAL ENGINEERING FOR THE DECADE 1966-1975

Report by the Committee on Research,
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FOREWORD

Presented in this report is a detailed listing of project areas in structural engineering in which substantial research effort is needed during the next decade. In an effort to place the contents of this report in proper perspective, and to give some indication of the relative significance of the numerous suggested research areas, it is appropriate to consider three general classes of research in structural engineering which can be identified as: (1) Existing research areas; (2) emerging research areas; and (3) implementation of new knowledge.

Existing Research Areas.—Continued attention must be given to the conventional areas of structural engineering research to improve the efficiency with which our existing structural materials, structural forms, and construction techniques can be used to produce structures that serve most effectively the purposes for which they are intended. Certainly there is room and need for improvement in practically all areas of conventional structural engineering endeavor, not only in the analytical techniques that are used, but also in the definition of the loads and environments to which the structures are subjected, as well as in the understanding of the properties and behavior of the materials and elements of which the structures are fabricated, and the design concepts, techniques, and structural forms in which the materials are used. These researches will produce further refinements in load definitions, analytical techniques, and design and construction procedures that will improve the versatility and confidence with which structural materials can be used; this in turn, will lead to greater economies in the use of these materials.

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Emerging Research Areas.—Although others will probably develop in years to come, at the present time it appears that the following areas of structural research, most of which are just now in the early stages of their development, show the greatest promise of providing the structural engineering profession with major advances.

Behavior and Design of Structural Systems.—Practically all of the past and most of the current research activity in structural engineering is concerned primarily with the behavior and design of structural elements as isolated pieces of an entire structural system. It should be recognized that individual elements of a structure do not behave independently of those to which they are connected. Rather, the entire structural system responds to the environment and the forces and motions to which the structure is subjected. Hence, greater attention must be given in the future to the behavior of the entire structural system and to the development of analytical and design procedures and concepts that take this into account. In this regard, it is appropriate that particular emphasis be given to the fact that most structures are dynamic systems, and that they should be analyzed and designed accordingly. Currently, with few exceptions, structural systems are analyzed and designed on the basis of a pseudo-static system presumed to be "equivalent" to the actual system. Technology has now advanced to the point that such simplifications are no longer necessary or justifiable, and it is proper that methods of analysis and design be updated to reflect more completely the behavior of the entire structure as the dynamic system that it really is.

Development of New Structural Materials.—Existing structural materials have served us well. However, new materials will be needed for structures in new environments, such as the ocean depths or outer space, to which structures of the future will be subjected. Furthermore, by the development of new materials, or the improvement of existing materials, the versatility with which engineers might use these materials will be increased substantially. For example, the development of an additive to give a plain concrete tensile strength as great or greater than its compressive strength would expand tremendously the capabilities of concrete as a structural material. Similarly, it is reasonable to expect that structural plastics, including foam materials, might be particularly adaptable to ocean and outer space environments. It is therefore considered of great importance that expanded interest in the development of new structural materials be undertaken.

Included within the same general area of effort is the need for the development of new connection methods for existing structural materials. Particular emphasis might be given to the development of adhesives which might be expected ultimately to replace welding, riveting, and bolting as connection methods for metal structures. Furthermore, adhesives would greatly simplify the use of composite and prefabricated structural elements.

Computer-Aided Design.—Significant progress has already been made in the application of electronic computational techniques to the analysis and design of structures. However, a major advance will have been achieved when computer-aided design procedures have been fully developed, and widely adopted by the profession.

After such a design procedure has been developed, it would be necessary only for the engineer to provide loads and general geometric and material properties, and then rely on the computer to perform all of the detailed processing tasks, such as analysis, proportioning, retrieval of tabulated data, optimization or suboptimization according to a variety of criteria, and coordination of the structural aspects of the structure with the other needs and requirements such as electrical and mechanical systems. Finally, the data generated by the computer could be used to produce drawings and specifications and/or be transmitted directly to a contractor for his bidding, scheduling, and automatic fabrication control purposes. With the achievement of such a complete man-machine structural design system, a major step forward in structural engineering will have been made.

Structures in New Environments.—Significant interest is now developing in the design of structures on the ocean floor and in outer space. It is important that these efforts be continued, with particular emphasis on the development of information definitive of the environments in which such structures may be placed, and on the development of materials and fabrication techniques suitable for these foreign environments. Constant liaison with the several governmental agencies that are primarily responsible for exploration in these areas should be maintained with the objective of feeding rapidly and continuously to the structural profession all of the information pertinent to the structural design problems in these areas.

Implementation of New Knowledge.—For many years the rate at which new knowledge has been produced has far out-stripped the rate at which this knowledge has been assimilated in practice. With the expectation of an increase in research efforts and the attendant substantial further increase in the rate of production of new information, some positive steps must be taken to speed the practical application of this information. No positive steps are proposed herein for the accomplishment of this objective, but it is reasonable to expect that the achievement of it might well be the joint responsibility of educational institutions, technical societies, organized professional groups, and the practicing engineer himself. Some universities are beginning to formalize continuing education programs for engineers and it seems possible that these formalized programs might be supported by the other groups cited above to stimulate the transition of information from the researcher to the engineer in practice.

SECTION 6: INTRODUCTION

Purpose of Report.—This study of the "Research Needs in Structural Engineering for the Decade 1966-1975" was prepared by the Structural Division Committee on Research at the request of the ASCE Committee on Research. It is intended for use by the latter committee in its effort "to draw up a report to set forth, on a national basis, "Research Needs in Civil Engineering 1966-1975." The following report is presented in an effort to assure that the structural engineering research needs of the next decade are adequately reflected in the general report on civil engineering research needs.

The primary purpose of the final report, which should present in clearly-defined terms the research needs for the entire civil engineering profession during the next decade, is used by the technical divisions of ASCE in planning and guiding their own programs of future effort. Furthermore, the report should present a framework within and a basis upon which the Society can move ahead in an organized and well-planned manner to stimulate and encourage research in those areas of the profession in which the need is greatest.

Research Personnel Requirements.—At the present time, an annual research budget of approximately $35,000 is required to support the work of one full-time supervisory level structural research engineer. On this basis, it is estimated that the equivalent of approximately 6,000 to 7,000 such full-time researchers will be required to carry out the research program proposed herein. In addition, at least twice and probably three times this many research assistants and support personnel will be needed.

To be placed in proper perspective, the preceding personnel requirement estimates should be compared with the number of people currently engaged in structural research. Unfortunately, it has not been possible to make a survey that would yield this information. However, a crude estimate indicates that the present level of research activity in structural engineering is approximately one third of that proposed herein. Hence, the proposed research program will require an increase of about 200% in the current level of effort.

Equipment and Facility Needs.—In view of the wide variety of the kinds of research involved in structural engineering, it is impossible at this stage to estimate closely and very difficult to estimate even crudely the cost of the increased facilities and equipment that would be required to accomplish the proposed research program. Some of the research is such that only office space, a library, and access to computer facilities is needed, whereas other research will require extensive and expensive specially-designed laboratory space and test equipment. As a crude average value, it appears that the capital investment in facilities and equipment is about $100,000 per full-time senior research engineer.

On this basis, if it is assumed that the presently available facilities and equipment are being used to capacity and, consistent with the estimate of the increase in personnel given above, that approximately 4,000 new full-time senior researchers will be required, then approximately $400,000,000 would be needed for new facilities and equipment. This estimate is probably excessive because not all existing facilities are being used to capacity; a more reasonable value is thought to be on the order of 1/2 to 3/4 of this number, or approximately $250,000,000, which is, coincidentally, about the same as the total 10-yr research program proposed herein.

SECTION 3: EXPLANATION OF RESEARCH NEEDS

Research Needs in Methods of Analysis and Design of Structures.—One of the primary components of progress in structural engineering is advancement in the methods of analysis and design of structures. Only within recent years has it been possible to analyze, with a reasonable degree of precision, any but the simplest structures subjected to static or pseudo-static loadings. In the same way that the method of "Moment Distribution" made possible the extensive use of continuous structures, the existence of large capacity high-speed electronic computers can now make it practicable to analyze and design highly indeterminate structures of new and unusual geometries subjected to complex time-dependent loadings.

As the availability of high-speed computers increase, it is important that methods of structural analysis and design be improved to take full advantage of the capabilities of this new tool. To use it efficiently and effectively it is necessary not only to develop more refined methods of analysis for complex structural forms such as shell and reticulated structures under a variety of specified load conditions, but also to define with greater precision the nature of the loads to which structures will be subjected in service. Further account must be taken of the statistical and probabilistic aspects of material properties, structural loadings, fabrication techniques, and workmanship quality and uniformity in the design of structures. Structural optimization techniques and methods for making reliability analyses of structural systems must be developed.

In the material that follows, an effort is made to identify and comment briefly on specific items in the previously mentioned general areas in which research is needed in the immediate future.

General Methods of Analysis.—The fact that structures of complex geometry are being built with increasing frequency must not be interpreted to mean that knowledge of the behavior of these structures is complete. Present methods generally require the introduction of many simplifying assumptions and, hence, represent the behavior of the structure in only an approximate manner. Even so common a structural form as a multistory building can be analyzed only approximately. Methods must be developed to improve our ability to define the resistance properties of such buildings, including the interaction of all structural components, and to compute their behavior both in the elastic and inelastic ranges under a wide variety of loading conditions. This is only one illustration of the inadequacy of present methods of structural analysis. Listed below, with brief comments, are several others:

1. Frame and Truss Structures: Methods should be developed to take into account, more completely than presently available methods will permit, the interaction under static conditions of all components of a truss or frame structure, including not only the primary structural elements, but also the floor systems, bracing systems, partition walls, etc.

Analyses of multistory buildings or complex truss systems based on idealizations as planar structures consisting only of the primary structural elements (i.e., beams, columns, and girders) cannot define completely the behavior of the entire system. Structures of this type are complex three-dimensional structures of interconnected elements, and should be analyzed and designed as such. Considerable emphasis must be placed on the force-deformation characteristics of the structure as a system, not only at levels of low elastic response but also under repeated and reversed deformations well into the inelastic range.

2. Shell Structures: Despite the increasing use of shell structures, considerable research is needed to develop methods of analysis and design of complex shell structures even for static loads. Such structures are usually efficient load-carrying systems; however, of the infinite variety of shell forms that are available, only a comparative few of the simpler types have been studied to any significant extent. Special attention must be given to shell stability problems, rib-stiffened plate and shell configurations, the effects of inelastic material behavior, creep buckling, and thermal effects.

3. Suspended Structures: Suspension bridges have long been used, and in recent years the use of cable-suspended roof systems and suspended shells for buildings has been increasingly common in cases where long unobstructed spans are required. Additional study is needed to predict the behavior of such suspended systems under a variety of loading and environmental conditions.

Of particular importance is the response of suspended systems of dynamic loads. The aerodynamic stability of such systems also needs further study.

4. Mass-Concrete Structures: Additional work is required to improve and refine the analysis of mass-concrete structures to consider properly the stresses and deformations produced by superimposed loads, temperature variations, shrinkage, creep, and foundation settlement.

General Methods of Design.—Structural design, while implicitly requiring a structural analysis capability, includes also concepts and methods unique to the design process. Those aspects of the general design process that are in greatest need of research in the immediate future are:

1. Loadings on Structures: Most structures must be designed to resist not only well-defined static loads but also, and frequently most importantly, dynamic loads as well. Included among the common dynamic loads are earthquake and blast-induced forces, winds, water waves, impact of moving vehicles and machines, etc. Methods that are now available and that will be improved and extended make it possible to analyze a structure under complex time-dependent forces. Therefore, it is important that these commonly-occurring dynamic forces be studied in detail and that methods be developed whereby these forces can be better defined as they vary spatially and in time on the structure to be designed. Basic concepts of probability and statistics should be introduced into these studies.

2. Reliability of Structures: The old concept of a factor of safety based on allowable stress levels in the individual elements of a structure is inadequate to define the reliability of a structure. New methods are needed which take into account the nondeterministic aspects of structural design (loads, material properties, fabrication techniques, methods of analysis, etc.) and the behavior of the entire structure as a "system" rather than as an assemblage of separate components. Further study is needed of such factors as the consequences of failure, errors in design, errors in fabrication and in erection, etc., on the required safety of a structure. How can a factor of safety reflect the nature of the loading (static, dynamic, single, repeated, reversed, etc), the type of material used, the type of structure, etc.?

3. Optimization in Structural Design: Increased economy and improved performances of structures could be achieved if methods were developed whereby the designer could readily determine the optimum combination of geometry, materials, and methods of fabrication for a given structural requirement. Important research is now beginning in the area of structural design optimization; a major increase in this effort is clearly justified.

4. Failure Criteria: Inadequate attention has been given to failure criteria, particularly for structures subjected to dynamic loads. Improvements in, and extension of, approaches such as that of Biot (shock spectrum) are urgently needed.

Use of Small-Scale Models.—Small-scale models as a tool of structural analysis and design have been used only to a limited extent. Such models can be used effectively as an aid to understanding the behavior under load of complex geometrical forms and, hence, in the formulation of methods of analysis and of design criteria for such structures. A substantial increase in research in this area is recommended. Additional work is needed to develop modeling materials and techniques that permit of valid extrapolation of results obtained in the model study to the behavior of the prototype.

Analysis and Design for Dynamic Loads.—The need for improved methods of structural design to resist dynamically applied loads is emphasized by the requirement for blast-resistant structures, by the losses in life and property (estimated at hundreds of millions of dollars per major earthquake) each year from earthquakes, and by the growing recognition of the need for additional information on the loading and response of tall buildings under wind loads. Efforts must be made to expand substantially the research effort in this area. It should not be inferred that such research can eliminate structural damage from major earthquakes, but it can result in improved methods of design and fabrication that will substantially reduce such losses.

It is impossible herein to examine even briefly the scope of the research needed in this area. It embodies all structural types (buildings, bridges, dams, shell structures, etc.) and all materials. Procedures must be developed for the representation of a complex real structure as a dynamic model, the behavior of which can be related to the behavior of the real structure. Attention must be given not only to elastic response of such a system but also to the influence of inelastic behavior on the dynamic characteristics of the structure. Research is needed on the energy-absorption characteristics of structures when responding to dynamic forces, the superstructure-foundation-ground interaction under dynamic response, and many similar problems.

The rapidly expanding field of surface transportation research will require also additional structural research. Because of the greatly increased speeds proposed for transport vehicles, response of structures to impact will need further study, and the proposed new elevated and buried systems will create new structural problems.

Substantial research has already been done in this area, but much more is needed. Except for relatively simple structural frames that respond elastically, our understanding of the dynamic behavior of structural systems is grossly inadequate. Not only must reliable methods of analysis be devised for more complex structures, but the results of these analyses must be used to formulate rational procedures for design of structures that will respond in the desired manner to dynamically applied forces.

Design of Towers.—Because power and communications transmission towers are used so extensively that they are mass produced, they deserve concentrated attention in comparison with other structural forms. Particular emphasis should be given to optimization of tower design and to improving the efficiency of connections and fabrication techniques. Economies that seem insignificant in terms of a single tower may become important when multiplied by the large number of such towers that are used.

The small quantity of data on measured strains and deformations of suspension bridge towers indicate a gap between design assumptions and actual performance. There is evidence to suggest that a detailed study (including extensive instrumentation) of the behavior of existing suspension bridge towers might lead to substantial economies in simular future towers.

Special Building Problems.—In addition to the more generally recognized areas of structural engineering research (which are evaluated in some detail herein), there are also numerous allied or related problem areas in which the structural engineer is frequently involved, although for which he is usually not solely responsible. Included in this latter category are the following: Aesthetics of structures, fire resistance, protection, and ratings; integrity of claddings; deflection limitations as determined by other than structural safety; building code provisions, etc.

Experimental Verification of Design Analyses.—Although there are many opportunities to do so, little effort has been devoted to the experimental verification of design analyses. Useful information could be obtained through an extensive program to study the actual behavior of real structures. By proper instrumentation at critical locations during construction, the strains and deflections under the various loading conditions can be observed and the validity of the design assumptions can be checked.

Estimated Cost.—The foregoing leads to this estimate of the cost of a 10-yr research program in methods of analysis and design:

Research Area	Cost
General Methods of Analysis	$12,000,000
General Methods of Design	12,000,000
Use of Small Scale Models	5,000,000
Analysis and Design for Dynamic Loads	6,000,000
Design of Towers	1,000,000
Special Building Problems	1,000,000
Experimental Verification of Design Analyses	3,000,000
Total	$40,000,000

Research Needs in the Application of Electronic Computers to Structural Engineering.—High-Speed electronic computers make it possible to analyze any structural system whose behavior can be formulated in mathematical terms. Present efforts to increase the usefulness of electronic computers to structural engineers by the generation of simplified computer languages (such as FORTRAN) and programs (such as STRESS and STRUDL) must be continued. However, probably the most important advancement in structural engineering would be the development of counter-aided design processes. It is entirely reasonable to expect that, within the 10-yr period being considered, research will lead to a complete man-machine system for the design of structures. The engineer would provide the loads, general geometric and material properties, and could then call on the computer to perform all the detailed processing tasks, such as analysis, proportioning, retrieval of tabulated data, optimization or suboptimization according to a variety of criteria, and coordination with other "trades" and requirements. The results generated from the computer would then be either accepted by the engineer or modified in any manner he sees fit. Finally, the data generated by the computer could be used to produce drawings and specifications, or be transmitted directly to the contractor for his bidding, scheduling, and automatic fabrication control purposes. To accomplish this objective will require a major research effort; however, it can and doubtless will be done. Such a capability would pay enormous dividends. Among the benefits to be derived are the following:

1. It would reduce the time required to prepare designs;
2. it would increase the ability of the engineer to consider alternate designs for a particular structure, leading to greater economy; and
3. it would increase the ability of the engineer to determine the influence of variations in design restrictions on the total structure.

A reasonable research program in this area will probably require an average of approximately $2,500,000 per yr, or about $25,000,000 for the 10-yr period.

An extensive research program to achieve these objectives is strongly recommended.

Research Needs in Masonry and Reinforced Concrete Structures.—Despite the extensive use of masonry and reinforced concrete, much additional information is still needed to improve the efficiency with which these materials are used, thereby making possible more economical structures and the design of structures of new and different geometrical forms. Recent innovations such as prestressed concrete, folded plate construction, and limit-design methods attest to the potential improvements that can result from research in this area. It is reasonable to anticipate further similar advances in the use of reinforced concrete if sufficient research effort is devoted to it.

Although considerable work is needed to improve our understanding of the behavior of masonry and reinforced concrete structures under working load conditions, probably the greatest deficiency in knowledge concerning such structures is in their force-deformation relationships under repeated and reversed loading conditions and their ultimate failure characteristics. This information is essential to the further development of limit-design methods and to the design of such structures to resist dynamically applied loads.

Presented below are brief discussions of problem areas in which existing research activity should be continued and expanded. Presented also are several areas in which existing research activity is either very limited or nonexistent, but in which extensive research holds promise for the achievement of significant advances.

Composite Construction.—Structural members of dissimilar materials are often used in bridges employing steel beams and a cast-in-place concrete deck. The composite structural action is dependent on the connection between the beam and the deck. New methods of making an attachment safely and economically between dissimilar materials and between elements of the same material should be constantly evaluated through research. Other investigations might include flexural members clad with a more corrosion resistant, higher strength, or cheaper material than the main core. Attention must also be given to the composite action of precast beams and slabs supported by them.

Reinforced Concrete Slabs.—The concrete slab has been an efficient economical floor system for decades. The current trend of building high-rise buildings of concrete is due partly to the development of flat plate floors and lightweight aggregates for concrete. Economy dictates that the floor be as shallow as possible. Adequate safety requires that the shear stresses around the column be held to specific limits. In attaining these economic, yet safe, engineering solutions, problems of analysis, deflection, shear, and cracking must be solved constantly.

Folded Plate Construction.—The folded plate consists of connected planes to form geometric shapes of greater stiffness and more visual appeal than a single-plane system. A three-dimensional sawtooth arrangement is an example. Presently available methods for analysis of the structural element can be improved, and evaluation of creep, shrinkage, cracking, temperature, and deflection characteristics are essential.

Limit Design.—This theory is based on the concept that each member of a structure contributes its theoretical ultimate load to the maximum strength of the complete structure. Sufficient rotational capacity near ultimate loads is necessary in redundant structural members if the structure is to reach its maximum load capacity. This rotation of members at near ultimate loads occurs at reinforcement yield locations and permits moments to be redistributed in the structure during additional loading. Many factors affecting this rotational capacity are yet to be evaluated.

Precast Structural Concrete.—The use of precast concrete for structures possesses many advantages. The elements can be factory fabricated with considerably greater control than exists at the construction site. Many problems of assembly are required research, particularly the proper connection of elements in the completed structure, to withstand the imposed forces. Another field requiring investigation is the amount this closer fabrication control can justify liberalizing the code requirements under which structural concrete is now designed and constructed. Research is also needed on the composite action of slabs and precast beams on which they are supported.

Prestressed Concrete.—Few developments have so revolutionized an industry as has the application of prestressing to concrete. There are still ways of increasing the economy of these prestressed sections—by the application of unstressed steel to control camber, deflection, and stress, by variation of the allowable stresses, and by new structural shapes. Remarks made regarding precast concrete also apply to most prestressed concrete because the latter is mainly fabricated in factories under controlled conditions.

Reinforced Concrete Columns.—While the theoretical action of this most important building component is understood, constant research has not fully evaluated the action of less-than-perfect, manmade columns. Action of dissimilar materials, steel reinforcement and concrete in the columns, splices, the action of the floor on the column, and variations of the member from a perfect geometric shape are departures from theoretical column. Research is needed to discover ways to economize on this building component by better understanding of practical column action.

Masonry Design and Practice.—Many walls are built of either plain or reinforced masonry. Because they are not monolithic units, but are comprised of many small units, special problems are created. Load-bearing capacity, shrinkage and cracking characteristics, heat transfer characteristics, lateral strength, ability of the joining mortar to transmit load, desirable properties of the mortar (strong material with a high modulus of elasticity or a weaker mortar with a low modulus), behavior of reinforced wall panels, improved methods of reinforcement and bond and anchorage of reinforcement are among the problems in need of further research.

Shear and Diagonal Tension.—Despite the past and continuing extensive use of reinforced concrete beams and slabs, understanding of the strength, behavior, and failure mechanisms of reinforced concrete members under combined bending and shear is still grossly inadequate, even in elements of conventional or "normal" proportions. The lack of understanding in these areas is magnified in deep members and in members subjected not only to bending and shear but also to direct stress. An extensive research program in this area is needed to develop a rational theory to explain the behavior of reinforced elements under combined stress conditions. Such a research program should make it possible to design reinforced concrete structures of more uniform resistance with increased economy.

Cracking of Concrete.—The cracking of concrete can be controlled to improve structural performance, but the best and most economical method of doing this is yet to be found. Methods of controlling this cracking are still under study and full success in this endeavor depends on fully understanding the cracking phenomena. There has been some agreement between investigators on the related variables, but little agreement on how these variables affect cracking. The natural phenomena of cracking is subject to great variation of width and spacing within the same specimen and this complicates the needed research.

Behavior of Reinforced Concrete Structures.—Most research is done on separate structural components, namely, columns, beams, girders, and slabs. The action of the component in a structure can be only approximated in laboratory studies. Study is needed on the components within the structure to better understand the interaction among the several structural components. The response of structures to dynamic loads such as fluctuating wind, earthquake, or blast is only now beginning to be studied. Continued research is needed especially in the field of high-rise buildings where the concentration of people and the responsibility for their safety is large.

Bond and Anchorage of Reinforcement.—The mechanisms of load transfer from reinforcement to the surrounding concrete is not yet fully understood. Additional information on this subject is needed, especially under conditions of repetitious loading and reversals of loading.

Torsion of Reinforced Concrete Members.—The inhomogenous nature of reinforced concrete poses special problems when designing to resist torsion. Further research is needed to explain rationally the behavior of torsionally-stressed reinforced concrete elements and to provide a basis on which to establish the most efficient type and pattern of reinforcement to resist torsion.

Tensile Strength of Concrete.—The versatility would be significantly enhanced if the tensile capacity of concrete could be substantially increased. Research should be continued and expanded to develop additives, dispersed reinforcement fibers, or other means to achieve a concrete of high tensile as well as compressive strength.

Reinforcing Materials and Methods.—Although conventional steel bar reinforcement has served well, new and better reinforcing materials and methods can still be found. A significant amount of research into the possible use of plastic fibers and steel fillings for reinforcement has already been done, but additional studies in this area are needed.

High Strength Concrete Structures.—Research is needed to investigate the behavior of and to develop design procedures for reinforced concrete structural members made of very high-strength concrete (approximately 10,000 psi compressive strength, or greater). Experience with very high-strength concrete is limited, and investigations are required to determine the applicability of current design procedures to structural elements made of high-strength concrete.

Deflection Predictions.—Improved and more reliable methods are needed to predict the load-deflection characteristics of reinforced concrete structural elements up to the point of incipient failure. Such procedures are required to make possible the study of the behavior of entire structural systems. They would be especially useful in the analysis and design of structures to resist earthquakes and blast forces, in which cases the structures are usually expected to deform plastically under the design loads.

Maintenance and Modification of Existing Structures.—The development of improved methods of repairing and strengthening existing reinforced concrete structures requires an expanded research effort in this area. If successful, such research could lead to major reductions in maintenance budgets. Substantial advances in this area have been made possible by resin bonding, but further improvements are still needed.

Estimated Cost.—The foregoing leads to this estimate of the cost of a 10-yr research program in masonry and reinforced concrete:

Research Area	Cost
Composite Construction	$1,000,000
Reinforced Concrete Slabs	2,000,000
Folded Plate Construction	1,000,000
Limit Design	3,000,000
Precast Structural Concrete	5,000,000
Prestressed Concrete	2,000,000
Reinforced Concrete Columns	3,000,000
Masonry Design and Practice	2,000,000
Shear and Diagonal Tension	5,000,000
Cracking of Concrete	2,000,000
Behavior of Complete Structure	2,000,000
Bond and Anchorage of Reinforcement	1,000,000
Torsion of R/C Members	1,000,000
Tensile Strength of Concrete	1,000,000
Reinforcing Materials and Methods	1,000,000
High Strength Concrete Structures	1,000,000
Deflection Predictions	500,000
Maintenance and Modifications	500,000
Total	$33,000,000

Research Needs in Metal Structures.—Despite the extensive use of metal structures, notably steel, there is much to be learned to refine further the use of existing structural metals and to develop methods of using new metals effectively and efficiently in structures. The continuing introduction of new high-strength steel and aluminum alloys (there are 200 different steels above A36), the requirements of new and unusual structural geometries, the growing interest in tubular structures, extreme environmental conditions, and other similar factors require a substantial increase in the research effort in this area.

The primary research needs in this area are summarized briefly herein. Space will not permit a complete evaluation of these problems; consequently, little more than short statements of the problem areas are given. In some instances, the indicated effort refers to a continuation and expansion of research efforts now in progress; in other cases, problem areas in which there is now little or no research activity are identified.

Compression Members.—The stability of metal compression members has long been the source of concern in the design of metal structures. This problem has been emphasized with the increased use of high-strength steels and

aluminum alloys in structural frames. In particular, additional study must be given to the influence of residual stresses on the stability of columns. The behavior of compression members in reticulated structures and of unsymmetrical compression members also needs further study. (Additional support is needed for the Column Research Council so that it can function more effectively as a discussion forum, stimulus, and coordinater of research in this area.)

Production and fabrication techniques result in distributions of residual stress that can vary widely as a result of the particular procedure used and the shape of cross section under consideration. A fundamental study of fabrication techniques as they influence the formation, magnitude, and distribution of residual stresses is required. The several welding procedures—flame-cutting, pre-heating and post-heating—should be considered. Objectives of the study must be to develop methods to predict the distribution and magnitude of residual stress patterns, and to reduce the magnitudes of these stresses thereby improving structural performance.

The role of residual stresses on the buckling strength of various shapes should also be studied. Such studies should include axial, as well as eccentric, loading.

In most structures of any magnitude, unsymmetrical compression members are purposely avoided because of the complications which they introduce. However, in many other structures, notably transmission towers and light roof trusses, it is impossible to avoid unsymmetrical sections without considerable expense. Improvements in the design of such components can be effected only when additional information becomes available on the strength of such elements.

Just as it is important that methods of analysis be developed to reflect the behavior of the entire structural system, so also should methods be developed to make possible the stability analysis of an entire structural framework. Most stability analyses are restricted to planar structures; research is needed on the true three-dimensional form. Furthermore, existing stability studies do not take into account in a rational manner the influence of dynamic loading.

Compression members are uniquely dependent on material properties. The rapid development of new materials has created a research need to relate significant material properties to stability. Both safety and economy require that these additional studies be undertaken.

Reticulated Structures.—Reticulated structures provide an efficient mechanism by which to span large areas and produce enclosures of great volume. Because of the high degree of indeterminacy, the efficient design of such structures requires great effort and accurate predictions of ultimate strength are practically impossible at present. In addition, consideration must be given during the design phase to the construction method and procedures to be used. Of particular importance are the connections of individual members in such a structure, the development of easy fabrication of subassemblages, and erection methods that would simplify the work in the field.

Complications introduced by considerations of buckling of the entire structure and of any part of the structure must also be considered.

Light-Gage Metal Structures.—Increased use of light-gage metal as the exterior panels of high-rise buildings has revealed gaps in our knowledge of the influence of the exterior covering of such structures. Ordinary design procedures do not consider the exterior structures as a primary structural element. Such elements do, however, contribute significantly to the lateral stiffness, damping, and vibration characteristics. Openings in light-gage exterior surfaces can have a considerable effect.

Contributions of the exterior coverings to the properties of structures must be evaluated to develop more rational design procedures. Primary among such considerations should be the required thickness and minimum attachment for effective use of these elements as contributing structural elements.

Light-Weight Alloys.—Light-weight metal alloys, notably aluminum, are becoming more widely used for structural purposes. Because the properties of these materials differ from those of steel, for which the background of knowledge from research and experience in civil engineering structures is greater, much additional research on structures made of light-weight alloys is needed. Of special importance in this area is the need for research on the fatigue strength of aluminum structures, including joints, and the application of plastic design methods to light-weight alloy structures. Further research is also needed on stability problems, especially those relating to thin-gage construction.

Maximum Load Design (Plastic Design).—In recent years significant progress has been made in the development of plastic-design concepts and methods for planar steel structures. The concepts, which have already made it possible to design structures with a more efficient use of materials, need further refinement, particularly in their application to highly indeterminate systems such as high-rise buildings. Furthermore, procedures should be developed for the application of maximum-load design concepts to three-dimensional structural systems (space frameworks).

A major study is needed on the application of plastic-design methods to certain classes of bridge structures.

"Core and Skin" Structures.—Improvements in structural design require that present and future materials be combined in such a manner as to produce new structural forms. One such concept is the "core-and-skin" structure in which vertical loads are carried by the core and lateral loads are carried by the skin. Both analytical studies and experimental investigations of such structures are needed. Analytical studies should investigate the behavior of these structures and the effect of the distribution of materials and the interaction of the various structural elements.

Future efforts should be directed toward the study of the possible application of a variety of structural materials in such structures, for example, high-strength steels, light-gage material, prestressed concrete, plastics, etc.

Flexural Members.—Although considerable research work has already been done on metal flexural members, the extensive use of such members requires that this effort be continued to improve further understanding of their behavior as influenced by the geometry of the member, the method of fabrication, the nature of the loading, and the properties of the material (or materials of which it is made). Particular emphasis should be given to studies of box girders, prestressed steel beams and girders, castellated beams, and curved beams and girders.

The most efficient use of the wide range of structural steels that are available frequently requires that two or more of these steels be used in the same member to take fullest advantage of the individual properties. Because the properties of the several materials in such "hybrid" beams may differ substantially from one another, the design of such members poses numerous problems in fabrication, stability, and behavior under a wide variety of load conditions (long duration loads, repeated loads, reversals of loads, etc.) that can only be answered through research. Further problems arise when "hybrid" steel beams are considered for use in composite construction with reinforced concrete, timber, plastics, or other materials.

Structural Connections.—Although riveting, bolting, and welding are currently the most common fabrication procedures for structural metals, these procedures have certain inherent characteristics that frequently impair the efficient use of material and restrict geometrical form. Fundamental work must be carried out to develop new concepts and techniques for the transfer of force in connections so that the strength properties of structural metals can be used to the maximum extent. This problem will require the effort of qualified people in widely different fields.

In addition, a major effort must be directed toward an evaluation of the behavior of existing structural connections when subjected to various environmental conditions. Despite considerable past research efforts, the influence of such conditions has been explored to only a limited extent.

Orthotropic Plate Structures.—Additional theoretical and experimental studies of orthotropic plate systems are needed. As new theoretical procedures are developed, they should be incorporated into optimization techniques to study the most efficient distribution of material for strength and economy.

Because such structures require considerable welding, the role of fabrication procedures and residual stresses must be incorporated in the studies undertaken.

Feasibility of application of this structural form in buildings and other structures should be considered.

Tubular Structures.—The use of tubular sections for structural members is becoming increasingly common. An extensive research program should be undertaken to supply the information needed to design properly connections involving such members (tubes to tubes, tubes to spheres, and tubes to standard structural sections). Typical structures in which tubular members may be used include buildings, sign structures, antennas, and off-shore structures. Both static and repeated loadings should be considered.

With the sudden increased interest in off-shore structures, a design environment has been created in which the civil engineer has little design experience. The design of connections built up from tubes is particularly complicated because of the radial flexibility of the tube wall which has a predominant influence on the stress distribution. The design can no longer be based solely on the conventional strength-design approach as commonly used in the design of connections of standard-type sections. The complicated joint-stiffness considerations must be taken into account.

Fatigue of Metal Structures.—With the introduction of many new materials, the development of new processes for joining materials, the increases in magnitude of loadings in such structures as bridges, and the development of more accurate and effective methods of analysis, the importance of recognizing the effects of fatigue in the design of structures has increased. There is a great need for the provision of data that can be used for the formation of more complete fatigue design specifications which will provide for the more important fatigue parameters. Studies of the behavior of members, connections, and structures under random as well as systematic loadings, significance of small fatigue cracks, and their detection must be considered. Such data will be of significant value to all groups vested with the responsibility for design specifications.

Fracture.—The entire field of fracture of structural metals demands attention. As new materials are developed at an ever-increasing rate, new applications for all structural metals are conceived and new environments are considered. For future developments it is essential that fundamental information on fracture and the parameters which define fracture limits be developed.

Mechanics of fracture propagation as influenced by stress distribution (including residual stresses), environmental conditions (including space environment, corrosive atmosphere and radiation) should be included.

Suspended Structures.—Cable-suspended structures, now commonly used in bridge construction, are finding use also in roof structures of large spans, as well as in buildings of new and unusual geometries such as the New York World's Fair pavilions. The use of cables as intermediate supports in building construction should also be expected. Further research on cable-suspended roof systems is clearly needed, not only in their analysis and design, but also in regard to the properties of the cable materials.

Estimated Cost.—The foregoing leads to this estimate of the cost of a 10-yr research program in metal structures:

Research Area	Cost
Compression Members	$ 5,000,000
Reticulated Structures	1,500,000
Light Gage Metal Structures	1,000,000
Light Weight Alloys	2,000,000
Plastic Design	1,500,000
"Core and Skin" Structures	1,000,000
Flexural Members	5,000,000
Structural Connections	5,000,000
Orthotropic Plate Structures	1,000,000
Tubular Structures	1,000,000
Fatigue	7,000,000
Fracture	7,000,000
Suspended Structures	2,000,000
Total	$40,000,000

Research Needs in Structural Plastics.—The use of plastics for structural purposes is in its infancy; however, it appears probable that, in time, plastics will become a primary building material. Plastics, including foam materials, are light in weight, easily formed, corrosion resistant, and easily transported; hence, it is logical to think of plastics for use in structures of unusual and irregular geometries, and in structures in outer space and in the ocean depths. Future structural types may well evolve from the advantages offered by plastics, for example, radar towers which can be designed to enclose and protect the antennas as a result of the electronic transparency of the material.

To realize fully the potential of plastics for structural uses will require the development by the plastics industry of materials possessing the strength, ductility, and deformation properties required of structural materials. The research required to produce these materials shall be assumed to be the

responsibility of the plastic manufacturing industry; to use these materials for structural purposes will require an extensive research effort by structural engineers.

Because the use of plastics for structural purposes is just beginning, it is impossible to foresee in any detail the nature of the problems that will arise as structural plastics become more readily available and more widely used. However, certain general areas of research in this area can be identified. Several of the more important of these areas that need immediate attention are examined briefly, as follows:

Time and Temperature Effects.—To be suitable for structural purposes, plastic materials, including reinforced plastics, must have structural properties that remain substantially stable for long periods of time and under a reasonably wide range of temperature. Although some variation in properties may be admissible, these variations must be defined so that they can be taken into account in design.

Behavior of Material under Long Duration Loads.—Although the significant properties of plastic materials may be substantially insensitive to time, these materials may undergo excessive deformation (creep) when subjected to high stress levels for long periods of time. Hence, information must be obtained on the "creep" characteristics of plastic materials to be used for primary structural elements.

Fatigue Behavior of Materials.—In the same way that the fatigue behavior of steel, aluminum, and reinforced concrete is important, so also must the behavior of plastic materials under a large number of load cycles be determined. Research must be undertaken to determine the influence of repeated loadings on the resistance properties of structural plastics.

Properties of Plastic Structural Elements.—In current practice, reinforced structural plastics are produced in the conventional shapes of I, WF, angles, etc. with discontinuous and randomly oriented fibers. Before extensive use of plastics for structural applications can be expected, research is needed to define the optimum shapes to utilize the high strength of reinforced plastics most effectively. Careful study of geometric-strength relationships should improve the relatively low performance of available structural plastics.

Connection of Plastic Structural Elements.—Methods must be developed whereby plastic structural elements can be quickly, simply, and reliably connected in the field. Methods of bolting and riveting produce undesirable stress concentrations in plastic members, and adhesive connections require chemical mixing, placing, pressing, and curing. The connection problem has prevented the use of plastics in many structural applications where the other unique properties of the material would be extremely valuable.

Anchorage of Prestressing Plastic Strands.—More efficient and reliable methods of anchoring fiberglass reinforced plastic strands used in prestressed concrete are needed. Present mechanical gripping devices develop only about one-half the strand strength, and bonding techniques develop no more than the inter-laminar shear strength capacity. The efficient use of the high-strength properties of reinforced plastics for prestressing is severely impaired by the inadequacy of the grips that are currently available.

Reinforced Plastics in Composite Construction.—Exploitation of structural plastics as components of composite systems has been inadequate to date. Improvements could be achieved in some structural uses by combining the most desirable characteristics of several materials. It is, therefore, necessary that research be undertaken to find methods of combining structural plastics with metals, concrete, and timber to create composite sections that take fullest advantage of the several properties of the structural materials.

Design in Brittle Materials.—There are numerous materials which, except for their property of brittleness, would serve well in many structural applications. Ceramics are illustrative of such materials. Research is needed to develop methods of overcoming or circumventing the shortcomings of brittleness and to formulate procedures for the structural use of this large class of high-efficiency materials.

Design Procedures for Plastic Structures.—Structural plastics, both plain and reinforced, are finding their way into unusual applications in the military, aerospace, and hydrospace fields and, more slowly, in civil structure uses. If advances are to be made in the use of plastics for structural purposes, it is essential that a practical design procedure consistent with the properties of these materials be developed. Various structures at the recent New York World's Fair served to emphasize the potential of plastics for structural applications. However, before widespread use of plastics as a conventional structural material can be accomplished, it is necessary that specifications for design in these materials be formulated. Although such design procedures or specifications cannot be formulated until the research proposed herein as well as other research yet to be identified is completed, a continuing effort must be made to synthesize the information on structural plastic design as it is accumulated.

Estimated Cost.—The foregoing leads to this estimate of the cost of a 10-yr research program in structural plastics:

Research Area	Cost
Time and Temperature Effects	$ 2,000,000
Behavior under Long Duration Loads	2,000,000
Fatigue Behavior	2,000,000
Properties of Structural Elements	2,000,000
Connections	4,000,000
Anchorage of Prestressing Strands	500,000
Use of Plastics in Composite Construction	2,000,000
Structural Use of Brittle Materials	1,000,000
Development of Design Procedures	2,500,000
Totals	$18,000,000

Research Needs in Wood Structures.—Timber is one of the oldest and most widely used of all structural materials. Its efficiency and versatility can be further enhanced by continuing at an increased level the research effort in this area. Listed below are specific problem areas in need of immediate study.

Composite Construction.—The potential of wood as an element of composite sections has not been explored fully. Design criteria should be developed for wood-concrete, wood-plastic, and other composites. Opportunity also exists to improve the efficiency and dependability of wood members by prestressing with steel and plastics. Design procedures for such systems are presently approximate.

Laminated Wood Structural Elements.—In recent years, considerable progress has been made in the development of laminated-wood structural

elements. Additional study is needed to describe accurately the behavior of laminated wood and wood composites. Of particular importance is the problem of failures of laminated elements in radial tension.

Flexural Members.—Modern architectural requirements frequently include the use of wood beams of variable cross section. Present design criteria for such members are approximate; research is needed to explain completely the behavior of such elements and to permit the formulation of rational design procedures. Particular emphasis should be given also to very deep laminated beams.

Plywood Panels.—Existing plate and membrane theories do not explain the observed behavior of plywood panels under the action of normal loads. It is, therefore, necessary that research be undertaken to develop criteria for the design of such panels.

Wood Shell Roofs.—Failures in wood shell roofs emphasize the need for additional research to explain the behavior of such roofs, thereby making it possible to develop rational design criteria.

Stability of Wood Members.—The stability of wood columns, arches, and beams must be studied to determine the lateral bracing requirements for timber structures. Currently available information on this subject is inadequate, and in view of the importance of the problem further research should be undertaken in the near future.

Fire Retardant Treatment.—Studies must be undertaken to determine the effects of the various fire retardant treatments on the strength of wood and on the properties of adhesive bonds used in wood laminates. Such research is needed to guide the development and use of fire retardant treatments and to provide a basis whereby cognizance can be taken of these effects in the structural design of such members.

Connections.—Continued research is needed to improve methods of connecting wood structural members, particularly in the case of field connections.

Estimated Cost.—The foregoing leads to this estimate of the cost of a 10-yr research program in wood structures:

Research Area	Cost
Composite Construction	$1,500,000
Laminated Elements	2,000,000
Flexural Members	1,000,000
Plywood Panels	500,000
Wood Shell Roofs	1,000,000
Stability of Wood Members	1,000,000
Fire Retardant Treatments	1,000,000
Connections	1,000,000
Total	$9,000,000

Research Needs in Buried Structures.—Interest in the design of underground structures has been stimulated in recent years by the need for structures capable of resisting the blast and shock effects of nuclear explosions. Except at relatively low blast pressure levels, adequate structural resistance can be obtained only through the use of underground structures. Briefly stated, the principal problems that are unique to such a structure under blast loading conditions are the following:

1. Determination of the time-dependent blast-induced vertical and horizontal pressures and soil motions in the free-field as functions of the size of weapon, its point of detonation relative to the free-field point of interest, and the properties of the soil at and in the vicinity of the free-field point in question.
2. Determination of the soil-structure interaction phenomena. To what extent and in what manner is the pressure on the soil-structure interface modified by the deformation or displacement of the structure?
3. Analysis of the structure-soil system as a dynamic system to determine the maximum structural stresses and deformations produced by the blast-induced forces and motions.
4. Determination of the time-dependent motions of points on the structure and the analysis and design of shock isolation systems for equipment mounted on the elements of the structure.
5. Analysis and design of structures buried in ice or snow, or both.

Research work is currently in progress on each of these subject areas. However, a greatly expanded program involving theoretical studies, laboratory model studies, and full-scale field tests is necessary to achieve the desired level of competence in this area within a reasonable time.

Although the primary impetus for this work comes from the need for blast-resistant protective structures, much of the information developed would also result in improved designs of conventional buried structures to resist only static loads, such as pipelines, culverts, tunnels, etc.

Estimated Cost.—The foregoing leads to this estimate of the cost of a 10-yr Research Program in Underground Structures[a]:

Research Area	Cost
Free-Field Effects	$ 2,000,000
Soil-Structure Interaction	10,000,000
Dynamic Analysis of Soil-Structure System	2,500,000
Shock Analyses	5,000,000
Structures in Ice and Snow	500,000
Total	$20,000,000

Research Needs for Structures in Outer Space.—Structures in outer space are no longer figments of wild imaginations; they will be realities within a few years. Hence, it is essential that structural engineers begin to consider such structures—their requirements and the nature of the environment in which they will exist. At the moment, an extensive program in this area probably is not justified, but certainly work must be begun. It is essential that close contact be maintained with the space scientists to obtain the necessary information concerning the environments in which such structures may exist (be it zero-gravity space or on the surface of the moon or a planet), and to assimilate this information as rapidly as it becomes available to develop structural forms,

[a] Includes only laboratory and analytical programs.

structural materials, and means of fabrication consistent with these environments and the functional requirements of the needed structures.

It is estimated that an initial research effort of $500,000 per yr would be reasonable and that it should increase to a uniform rate of about $1,000,000 per yr as additional basic data with which to work becomes available.

Research Needs in Underwater Structures.—The growth of the world's population and the attendant food and industrial needs may soon deplete land-based natural resources to the point that we shall have to "harvest" from the sea and "mine" from the ocean bottom. Indeed, it has even been suggested that cities may be built beneath the sea; experiments are now being conducted on the ability of men to live for sustained periods of time on the ocean floor.

Research should be undertaken now to determine the loads to which undersea structures will be subjected and to develop materials, structural forms, and methods of fabrication and construction that will be consistent with the highly corrosive, high pressure, underwater environment in which such structures will exist.

Although the foregoing comments imply deep underwater structures, it should not be inferred that problems no longer exist in relation to structures in reasonably shallow water. Additional work is needed on the design of such structures for wave action, corrosive effects, and earthquake and blast-induced pressure and shock loadings. Further studies are also required on mooring problems as well as on foundation problems in both the shallow and deep ocean environments, although these latter areas are probably not within the preview of the Structural Division.

An initial research effort of about $500,000 per yr appears reasonable. As additional information becomes available, the effort should be expanded accordingly, probably at a rate of approximately $1,000,000 per yr.

Research Needs to Develop New Structural Materials and Geometrical Forms.—As in the past, new, improved, and more efficient structural materials and geometrical forms will automatically be developed as a by-product of other structural and materials research. However, the rate of advancement in these areas could be increased significantly by a carefully organized and well executed research program designed specifically for this purpose.

A detailed examination of nature's structures, some of which are made of very ductile materials and others of which are made of very brittle materials, might well give rise to new and more efficient structural forms and materials. Furthermore, it has been suggested that pressure-supported balloons, tents, tires, and rafts are small structures, the concept of which might be applicable, perhaps with modification, to major civil engineering structures. Engorging hollow structures or structural members with air, gas, or fluids under pressure is a means of prestressing and stress distribution that has been exploited to only a limited degree. Extension of these principles using durable envelopes and well-sealed fluids could open new applications.

Previous reference has been made to the need for further research in "composite construction" which involves the use of two or more separate materials as components of the same structural element. Research is also needed in the area of "composite materials" in which one material is finely subdivided and mixed with another material to create effectively a third material. This field is related to the structural uses of ceramics, glass, and other brittle materials that were mentioned elsewhere herein.

A reasonably ambitious research program in this area would be approximately \$2,000,000 per yr on a continuing basis.

SECTION 4: IMPLEMENTATION OF NEW KNOWLEDGE

Although it is perhaps inappropriate to list the "Implementation of New Knowledge" as a research area, the Structural Division Committee on Research believes strongly that a well-conceived program to disseminate knowledge gained through research and to promote its use in structural engineering practice is essential. Even at the present time, the lag-time between discovery in the laboratory and implementation in practice is unacceptably long. If research activity is to be accelerated to the levels proposed herein, this implementation lag time will increase alarmingly unless positive steps are taken to prevent it.

It is beyond the scope of this report to propose in detail a program to overcome this difficulty. However, the following observations and suggestions are indicative of the kinds of things that can be done to alleviate this problem.

Experience has shown that active ASCE committees can do much to expedite the incorporation of new knowledge into design practice. Perhaps even more significant have been the efforts of the various research councils whose task committees guide specific research projects. The inclusion on these committees and councils of members from practice and from specification writing groups (in addition to university and research laboratory personnel) can do much to stimulate and facilitate the rapid use of new research results. Hence, additional support of such groups as the Column Research Council, the Research Council on Riveted and Bolted Structural Joints, the Reinforced Concrete Research Council, the Welding Research Council, etc., is recommended.

ASCE committees, working in cooperation with these councils, should be supported in the preparation of surveys, guides, and commentaries in their particular fields of specialization. The ASCE-WRC "Commentary on Plastic Design In Steel" is an example of the highly effective work that these groups can accomplish.

To avoid early obsolescence of young engineers, extensive programs of continuing education for practicing engineers must be developed. Such programs are probably not the sole responsibility of any one individual or group, but will require the coordinated efforts of the universities, the individual engineer, his employer, and perhaps also the professional engineering societies. Continuing education can no longer be left to chance; the inauguration of a well-defined, comprehensive program will be required.

It should also be noted that frequently research programs could profit significantly through international cooperation. Universities and research laboratories in the United States and abroad should be able to engage in coordinated research on subjects of mutual interest. Such cooperation would not only serve the interests of the technical community but would also enhance international relationships.

The quantity of money that should be invested in the kinds of programs suggested above is difficult to assess. It is suggested, however, that approximately 2% to 3% of the total research budget would be appropriate for this purpose. On this basis, a value of \$500,000 per yr is recommended.

Respectfully submitted,

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